EXHAUST FILTER REGENERATION REGIME METHOD AND APPARATUS

The invention relates to an exhaust filter regeneration regime, method and apparatus for example for use in a diesel engine exhaust stream.

Such equipment is used in the removal of carbon monoxide, hydrocarbons and NOX pollutants and particulates made in exhaust systems.

In known systems, soot removal is usually achieved most effectively through the use of a filter. Regenerated traps, such as CRTs (Continuously Regenerated Traps), work on the principle of retaining soot particles within a ceramic or silicone carbide filter often termed a diesel particulate filter (DPF), which collects the soot particles within porous walls of the honeycomb structure of the filter. The accumulation of this soot within the surface of the filter increases the backpressure of the filter, which then requires the filter to be regenerated.

Regeneration is achieved when the exhaust temperature reaches above around 600°C at which point the component of the exhaust gas stream reacts with the soot creating an exothermic reaction, which increases the trap temperature as soot is oxidised and burnt away. The regeneration occurs at a lower temperature in the presence of a catalyst.

The temperature of the exhaust gas and filter are critical to the regeneration process, which lead to various problems with the technology. For example, for certain engine duty cycles it is not possible to achieve an exhaust gas temperature which enables unassisted regeneration.

It is known to reduce the regeneration temperature by introducing a catalyst component upstream of the filter, which reacts with the upstream exhaust gas to create an NO_2 enriched atmosphere. This stimulates the regeneration burning process enabling regeneration temperatures to be reduced to around 380°C. There are, however, cases where the engine duty cycle is such that exhaust stream temperature never exceeds the 380°C regeneration target temperature and, therefore, other approaches are required to assist with the regeneration.

One known solution to this is set out in "Particulate Trap Technology for Light Duty Vehicles with a New Regeneration Strategy" Zikoridse et al, SAE Technical Papers Series No.2000-01-1924, in which exhaust gas flows through a heating module having a convection section followed by a radiation section before entering a particulate trap to raise the trap temperature. Alternatively, it is known to provide additional heating local to the filter to increase the approach temperature to enable regeneration, or to rely on fuel born catalysts. Auxiliary heating has drawbacks, as it requires more complex links to the vehicle's onboard power system, which in some cases will not be sufficiently sized to cope with the additional load; this also adds expense and maintenance difficulties. Fuel born catalysts, on the other hand, achieve the same result, however, there are growing concerns regarding the further emissions which are produced during this regeneration process.

Yet a further known solution is described in the presentation "Demonstration of the effectiveness of a NOX absorber and particle filter system on a light-duty diesel vehicle" McGill *et al*, Oakridge National Laboratory, presented at Windsor Workshop 2001, Windsor, Ontario. According to that presentation

fuel can be injected into the exhaust stream allowing catalytic reformation. However, if fuel is injected at too high a rate, it will slip past the catalytic converter without reacting, producing unwanted emissions such as white smoke.

Further problems can arise with the known systems; the regeneration regime is heavily dependent on temperature and hence on vehicle type and usage, for example vehicle duty cycle. Accordingly, before a soot filtration system can be fitted it is necessary to understand the engine's duty cycle to model the temperature profile of the exhaust gas to gain assurance that it will in fact regenerate the filter. This adds further problems because, for example, in a bus application the bus may have the temperature trending compiled on a motorway route where it is found to reach the correct regeneration temperatures. However, it may subsequently be assigned to an inner city route where exhaust temperatures are not sufficient for regeneration. Specifically, the best temperature across the catalytic converter can be achieved after a period of high engine load followed by a period of idle. Under these conditions the exhaust components are already hot and there is oxygen available to oxidise the fuel. However, if the idle period is extended such that the engine starts to cool, it is then more difficult to maintain the temperature of the front of the catalytic converter. In particular, under cool engine conditions, such as low duty cycle operation, the heat to vaporise the fuel is taken from the front of the catalytic converter. The vaporised fuel progresses further into the catalytic converter where it is oxidised. The resultant heat is conducted to the front of the catalytic converter which in turn is used to vaporise more fuel. A problem arises if too much fuel is injected, however as the front of the catalytic converter is quenched leading to the collapse of temperature rise.

The invention is set out in the claims.

As a result the invention allows implementation of the control strategy that is adaptable to multiple usages and duty cycles.

Embodiments of the invention will be described, by way of example, with reference to drawings of which:

Fig. 1 is a schematic block diagram showing an engine implementing an exhaust filter regeneration regime in accordance with the present invention;

Fig. 2 is a flow diagram demonstrating the steps implemented in the regeneration regime control strategy;

Fig. 3 is a flow diagram demonstrating the steps implemented;

Fig. 4 is a schematic block diagram showing a further improved approach to enhancing the regeneration regime;

Figs.5a and 5b are views of the injector head of the present invention, and;

Fig.6 is a schematic view of the electric catalytic heating element.

In overview, referring to Fig. 1 which shows in block diagram the principal components of an engine incorporating the system according to the invention. It will be seen that air is fed from inlet manifold 10 to an engine 12 from which

the exhaust is fed to an exhaust manifold 14. The exhaust stream then passes through exhaust conduit 16a to a catalytic reducer 18 for reducing CO and HC. The reduced exhaust stream then passes via exhaust conduit 16b to a diesel particulate filter (DPF) 20 where particulate matter such as soot is removed from the exhaust stream and the exhaust stream passes through exhaust conduit 16c.

A fuel injector 22 is mounted in the exhaust conduit 16a close to exhaust manifold 14. Alternatively the fuel injector 22 may be mounted directly in the exhaust manifold 14, to benefit from highest exhaust stream temperature. The fuel metered by the fuel injector 22 into the exhaust stream is oxidised by the catalytic converter 18 thus providing heat. The heat assists in raising the temperature of the DPF 20 to an appropriate level to allow combustion in conjunction with the oxygen present and beyond. As discussed in more detail below significant temperature increases up to the required level of approximately 550^{O}C , but more preferably temperatures of 650 to 700 ^{O}C are available by this approach. Temperatures above this range can have the effect of damaging the catalytic converter.

The system further includes a regeneration controller which can be separate from or part of an engine control unit ((ECU) 24 which controls the fuel injector 22 and also receives signals from sensors 26, 28, 30, 32, 34, 36, 38 and 40 as described in more detail below. Based on the sensed signals the ECU 24 implements a fuel injection strategy by fuel injector 22 to obtain the desired level of regeneration of DPF 20. In particular the sensed signals are used to determine when to switch fuel injection on and off and hence commence and terminate regeneration. Fuel injection start is triggered when the DPF is

detected to exceed a predetermined particulate load and the relevant temperature conditions are detected for commencement of the catalytic reaction with the injected fuel in the catalytic converter 18. Similarly, fuel injection is terminated when the particulate load is detected to drop below a predetermined threshold or when the temperature conditions are detected as being insufficient to support regeneration. The particulate load is determined as a function of the pressure drop across the DPF 20 and mass flow through the engine and the temperature detected at the catalytic converter 18. The ECU 24 also controls the fuel injection regime via fuel injector 22 to ensure that an appropriate regeneration level is attained. In particular fuel injection is controlled as a function of the temperature of the catalytic converter 18 to avoid slippage of unburned fuel past the catalytic converter resulting in unwanted emissions in the form of white smoke, resulting from excessive injected fuel.

As a result of this approach a method of regeneration is provided which is controlled entirely by on-board components requiring no operator involvement and which can be achieved for any operating vehicle's duty cycle. In particular it is achieved by artificially increasing the system operating temperature to above $550^{O}C$ to ensure that soot is burnt off by virtue of the high pressure fuel injection regime providing an increased exhaust gas temperature downstream of the catalytic converter 18. As described in more detail below, fuel may be injected at high pressure (100 bar) or low pressure (2 bar) dependent on the operating conditions of the engine.

The specific arrangement and strategies are discussed below together with further optimisations.

Referring to Fig. 1 in more detail, the catalytic converter 18 comprises a high platinum load metal catalyst of a cordierite metal or silicon carbide material with mineral wash coat which is found to reduce CO and HC by up to 95%. The DPF 20 is a silicon carbide filter found to reduce mass particulate by 95% and nearly eliminate visible black smoke. The sensors comprise an inlet manifold absolute pressure (IM_{PA}) sensor 26 and an inlet manifold absolute temperature (IM_{TA}) sensor 28 provided on the inlet manifold 10. An engine speed (ES) sensor 30 is provided on the engine 12, or at the inlet manifold to measure cylinder inlet manifold pressure variation, which fluctuate each time the cylinder ports open hence representing engine speed. A temperature sensor 31 is provided for sensing the temperature of exhaust gas (T1) exiting the engine exhaust manifold 14 before the fuel injector 22, with a further temperature sensor 32 T_{CI} on the entry face of the catalytic converter. A sensor 34 senses the temperature of gas at the exit face of the catalytic converter 18 (T_{CO}). Sensor 36 senses the pressure at the inlet to the DPF 20 allowing the pressure drop (P_{DPF}), with respect to atmospheric (i.e. pressure of the DPF outlet), across the DPF to be measured. Sensor 40 senses the temperature T_{DO} of gas exiting the DPF 20. The sensors comprise elongate probes extending into the body of the component whose temperature is sensed. The sensors extend radially into the component such that the axial position of the sensor can be determined exactly. This is of importance, for example, when it is necessary to obtain the temperature at each axial end of a component.

The manner in which the arrangement and particular sensor values are used in implementing the control strategy of the present invention can be further understood with reference to Fig. 2.

In block 200 the ECU monitors whether the particulate load on the DPF 20, F_{load}, exceeds a predetermined threshold. The value of F_{load} can be derived from:

1. $F_{load} = c\,(P_{DPF} * IM_{TA})/(ES * I_{MPA})$

Where c is a constant that can be calibrated during development of the system or derived from a lookup table.

Equation 1 represents the relationship between pressure drop across the filter P_{DPF}, mass flow and the particulate load. P_{DPF} increases as the filter becomes loaded with carbon until it is necessary to perform a regeneration of the filter to remove the carbon. However, as P_{DPF} is also proportional to the mass flow of gas through the filter it is necessary to normalise P_{DPF} against exhaust mass flow.

The exhaust mass flow is determined by the quantity of air taken in on each engine stroke which in turn determined by the temperature of the air at the inlet manifold (IM_{TA}) and its absolute pressure (IM_{PA}) and the engine speed (ES). The amount of air taken in will fall proportionally with increasing IM_{TA} and increase proportionally with increasing IM_{PA} and ES. This is reflected in Equation 1 above. The threshold value which F_{load} must exceed to trigger regeneration may represent full particulate loading of the filter or partial particulate loading of the filter and may either be stored as a constant in the control software or calibrated during development or installation.

It will be appreciated that alternative manners in which F_{LOAD} can be monitored are possible. For example the peak values P_{DPF} can be monitored to identify the significant trends. For example if the peak values are generally increasing then this can be identified as a result of the particulate load threshold having been reached. Appropriate behaviour can be calibrated allowing such recognition. In this case the short term fluctuation in P_{DPF} resulting from opening and closing of the exhaust valves in the engine cylinders can be disregarded, as only the maximum values are derived. A curve of maximum values can be constructed by interpolating between successive maximum values. As a result the particulate load can be determined without reference to the engine speed.

In block 202 the ECU 24 further determines whether the catalytic converter 18 is at a suitable temperature for the combustion of fuel injected into the exhaust stream to take place. In particular, as the catalytic converter will only stimulate oxidation of the fuel at a high temperature above approximately 230^{O}C the system checks that both the input and output temperatures T_{CO}, T_{CI} exceed the threshold temperature. If the particulate load and catalytic converter temperature both exceed the respective thresholds then block 204, the ECU commences the fuel injector regime. The system then monitors for a trigger event which will terminate the regeneration process. In block 206 the system monitors whether F_{load}, as given by Equation 1 above, falls below a lower threshold representing an appropriate reduction in the particulate load. If it has dropped below the threshold then in block 208 fuel injection is terminated. The system further monitors in block 210 for a reduction in temperature of the catalytic converter 18 such that combustion of the injected fuel will no longer take place as a result of which fuel injection will not be triggered. In particular the system can monitor to establish whether T_{CO} and T_{CI} fall below a lower

temperature threshold which in this case may be the same the $230^{O}C$ threshold value for triggering fuel injection in block 202. If so then once again in block 212 then fuel injection is aborted. As a result of abortion of fuel injection the required temperature rise cannot be achieved. It will be noted that once the catalytic converter is at a high temperature following fuel injection it is possible to maintain the required T_{CO} even if T_{CI} drops such that it may be desirable simply to monitor to establish whether T_{CO} drops below the threshold. Alternatively it will be seen that the fuel injection regime can be varied dependent on the temperature difference across the catalytic converter providing an accurate reflection of the temperature regime within the catalytic converter.

Drops in temperature of the catalytic converter can take place for various reasons, for example because of the duty cycle of a vehicle. One specific example would be the decrease in exhaust temperature if the engine load of a vehicle decreased. The temperature T_{CO} can further be monitored to identify when the catalytic converter temperature exceeds a damage threshold.

As an alternative approach, regeneration can be terminated if T_{CO} deviates from a T_{CO} setpoint which the system is attempting to achieve by fuel injection (as discussed in more detail below), for example by more than $30^{O}C$ for more than 10 seconds.

In block 214 the system further monitors to establish whether a time-out condition has taken place. Accordingly a timer is instigated upon commencement of the regeneration process at block 204 and if this exceeds a

threshold value, for example 5 minutes, then in block 216 fuel injection is once again terminated.

The system further monitors in block 220 to establish whether the temperature T_{DO} of the DPF 20 exceeds a self-sustaining threshold. When regeneration has been triggered a rapid increase in the temperature of the DPF is seen such that a high T_{DO} indicates that regeneration has been initiated and fuel injection can be terminated. As regeneration is a self-sustaining exothermic reaction no further fuel injection is required although it may be desired to introduce a level of fuel injection necessary to sustain regeneration for example at a lower level than that required to initiate regeneration, but sufficient to maintain the exhaust stream temperature at the desired level.

The system further monitors in block 222 to establish whether the temperature T_{DO} of the DPF 20 exceeds a safe working threshold, for example 1000°C. When T_{DO} exceeds the present working threshold fuel injection and/or regeneration is halted and an alarm condition indicated at block 224.

It will be appreciated that the fuel injection regime in block 204 is preferably controlled so as to achieve optimum efficiency and emissions reduction. In particular it is found that if too much fuel is added the fuel passes straight through the catalytic converter 18 without oxidation resulting in white smoke and also having a quenching effect on the catalytic converter, reducing its temperature. For example only a small amount of fuel should be added at the initiation temperature of 230^{O}C but as the temperature increases a high rate of fuel injection can be tolerated. An appropriate control strategy can be further seen with reference to table 1 and Fig. 3.

T_{CO} setpoint (°C)	T_{CO} setpoint ramp rate (°C/s)	Maximum time (s)
Up to 270	1	40
270 to 300	2	30
300 to 470	3	56
470 to 490	2	10
490 to 550	1	10
		146

Table I

In block 300, upon commencement of the fuel injection regime, the T_{CO} set point is set as the measured value (reaching 230°C). From a look-up table corresponding to Table I, the corresponding ramp rate can derived for that T_{CO} set point as 1°C per second. As a result the fuel injection is controlled to provide an increase in T_{CO} at that rate. This can be done, for example by varying the amount or frequency of fuel injection. Where the injector is switched on for a short period every 20ms, the period for which the injector remains on can be varied to meet the required amount of fuel into the exhaust. This period can be determined from a further look up table, for example calibrated upon development of the system or can be determined using a feed-back approach such as a PID (proportional/integral/derivative) control algorithm as a result of which the metering of fuel injection will be rapidly tailored to converge the temperature rate with the desired value. The amount of fuel injection may be reduced for situations where the engine speed and load are high, thereby preventing unwanted pass through of fuel. As such table 1 may vary in an additional dimension with engine speed and/or load.

The system continues to measure T_{CO} and in block 302 monitors to establish whether the measured T_{CO} has met the next set point (in the first instance 270^{O}C from Table I). If so at block 304 the T_{CO} setpoint is set to the next set point value (i.e. 270^{O}C) and the set point ramp is determined accordingly. In the examples shown, the set point ramp is increased to 2 degrees per second and the fuel injection regime metered accordingly to achieve this. As a result it can be seen that the ramp rate is slow initially but then increases as the catalytic converter temperature increases and more fuel can be oxidised. The system also checks at block 302 to ensure that the period during which fuel injection has been metered according to the ramp rate does not exceed a time-out period which can be individually determined for each set point value, as set out in Table 1 and is set at the expected time taken to reach the next setpoint or slightly longer. If so regeneration is aborted as the desired temperature rate increase cannot be sustained to initiate regeneration.

The process is repeated until T_{CO} reaches its upper temperature level e.g. 550°C at which point regeneration should be triggered. It will be seen that the set point ramps downwards again as T_{CO} approaches the upper limit to ensure that overshoot is avoided and reduce the risk of production of white smoke from unburned fuel. When setpoint T_{CO} reaches 550°C, fuel injection can be aborted, so as not to exceed the setpoint value. This may be appropriate in situations where regeneration is occurring as a self sustaining exothermic reaction. However, situations may arise where regeneration is not self sustaining and as such it will be necessary to inject fuel to sustain the 550°C set point i.e. at a 0°C/s ramp rate. Again, the rate of fuel injection is dictated by both the engine speed and load and the temperature T_{CO}. It will be seen that the time out period for the higher temperature values is significantly reduced again to avoid over-

injection of fuel and providing a maximum time for the fuel injection regime of the sum of the maximum permitted times for each individual step increase.

As a result, once initiated, fuel is injected such that a rapid temperature rise is achieved across the catalytic converter 18 so as to increase the probability of a successful regeneration. The possibility of slippage of fuels through the catalytic converter, resulting in unwanted fuel omissions presenting as white smoke is avoided by insuring that fuel is not injected at too high a rate and this is achieved by deriving a relationship between rate of temperature increase (and hence fuel injection) and catalytic converter temperature. As discussed above it will be appreciated that additional parameters can be incorporated to determine the ramp rate, for example increasing engine speeds as at high speeds the duration time of the fuel in the catalytic converter is reduced such as the fuel injection rate may need to be decreased. The temperature of the catalytic converter can also be monitored at more than one point through the length of the converter to allow optimisation of the fuel injection rate.

An alternative fuel injection rate strategy can be implemented, based on a known maximum injection rate. The fuel injection rate is set so as not to produce fuel slippage or exceed a maximum temperature. The maximum rate of fuel injection is given by the following equation:

2. $$FR=100 * FRES * FRT1 * FRT_{CI} * FRT_{CO}$$

FR is the final fuel injection rate in ml/sec, at a specific engine operating conditions. FRES is the fuel injection rate with respect to measured engine speed. FRT1 is the fuel injection rate with respect to engine exhaust manifold

temperature. FRT_{CI} is the fuel injection rate with respect to T_{CI}. FRT_{CO} is the fuel injection rate with respect to Tco.

The final amount of fuel injected is therefore dependent on the operating temperature at the engine exhaust manifold, the temperature across the catalytic converter and the engine speed. The final fuel injection rate is trimmed back progressively when the maximum operating temperature of the catalytic converter is approached. As a result a desired and controlled rate of temperature rise is obtained even during rapidly changing engine conditions when an engine is in use.

The fuel rate with respect to each of these parameters is determined from a look up table which is entered in ECU 24 to suit the type of vehicle and application of the vehicle. Examples of the look up tables are as follows, where each parameter of the table is derived dependant on type and application of vehicle, engine size or any other appropriate parameter.

FRES = Fuel rate with respect to Engine speed (rpm)															
0	256	512	768	1024	1280	1536	1792	2048	2304	2560	2816	3072	3328	3584	3840
0	0	100	100	90	80	70	40	30	20	10	0	0	0	0	0

FRT1 = Fuel rate with respect to T1°C															
0	64	128	192	256	320	384	448	512	576	640	704	768	832	896	960
0	0	50	100	80	60	40	20	0	0	0	0	0	0	0	0

FRT$_{CI}$ = Fuel rate with respect to T$_{CI}$°C															
0	64	128	192	256	320	384	448	512	576	640	704	768	832	896	960
0	0	0	0	10	20	40	60	80	90	100	100	70	0	0	0

FRT$_{CO}$ = Fuel rate with respect to T$_{CO}$°C															
0	64	128	192	256	320	384	448	512	576	640	704	768	832	896	960
0	0	0	0	10	20	40	60	80	90	100	100	70	0	0	0

Table 2

From the above equation 2, it will be appreciated that when one or more of the parameters in table 2 is zero then the final fuel injection rate is zero. This provides a system fail-safe whereby, no fuel is injected when the conditions are not optimum for regeneration.

As can be seen from table 2, typically the maximum fuel rate is designed to be highest when the engine has been working hard and the engine core temperature is high but then the engine goes to a period of idle. When idling the oxygen content of the exhaust is high allowing larger amounts of fuel to be burned. The maximum fuel injection figure peaks when both the front and rear of the catalytic converter are at optimum temperature, T_{CI} and T_{CO} respectively, and the amount of fuel injected is reduced if the catalytic converter temperature is too high, to prevent damage to the catalytic converter. Moreover, fuel injection is only enabled when the filter back pressure F_{load} is above a threshold, as

discussed above. This F_{load} parameter may be entered into equation 2 as a binary 1 or 0 product term, thereby providing a further fail safe mechanism.

It is found that high pressure fuel injection, for example, 100 bar gauge is effective as this creates the most effective dispersion and atomisation of the injected fuel in the exhaust manifold and exhaust stream. An injection repetition rate of 50 hertz allows an appropriate degree of control. In general circumstances the oxygen content of the exhaust gas will be sufficient to allow regeneration but of course additional steps can be taken to ensure that sufficient oxygen is present, in the catalyst if necessary.

Alternatively, a compressor (not shown) is used to deliver air, at a typical pressure of 2 bar, to an inlet 70 of an injector head 22, shown in side cross-section in figure 5a and in end view in Fig. 5b. The injector head is mounted radially in the exhaust gas stream in conduit 16a between sensor 32 and the entry face of the catalytic converter and directs fuel in an axial direction aligned and common with the flow direction of exhaust gas in the conduit. The fuel is metered, for example, via a peristaltic pump (not shown) of the type supplied by Rietschle Thomas UK Ltd, or any appropriate pump which allows on demand constant ml/minute metering to a fuel exit point 52 adjacent an air exit aperture 54. The peristaltic pump is driven by a stepper motor with high step resolution so that the fuel rate can be finely controlled.

In operation compressed air enters the injector head 22 via air inlet 70 and fuel enters the injector head via fuel inlet 72. The air and fuel pass to respective exits 54, 52 via discrete passages 74, 76. The air and fuel mix at the junction of the exit points. In a preferred embodiment, after fuel finishes flowing, air flow

is maintained for a short period, for example, five seconds, to ensure that all remaining fuel is dissipated. Such an arrangement ensures that fuel is effectively atomised and dispersed by the rapid and turbulent air flow caused by the air flow through the air exit aperture, whilst allowing ml delivery of fuel to the catalytic converter. Furthermore the air acts only as a means of dispersing the fuel rather than propelling the fuel. The corresponding low-pressure operation ensures that fuel entrained in the compressed air and mixed in the conduit is not, for example, injected at high speeds through the converter such that it hits the high temperature TPF which of course would present a significant hazard. Furthermore the fuel can be injected directly from existing fuel lines or the existing fuel tank and an additional holding tank is not required.

It will be appreciated that operation of the system can be further improved by maintaining a history of vehicle operation and regeneration regime. This can be used, for example, to improve the control strategy in various ways. For example it may be observed that regeneration is more efficient at higher or lower catalytic converter temperatures such that the relevant trigger points can be adjusted accordingly. Alternatively it may be observed that a higher or lower DPF pressure drop corresponds to completion or initiation of regeneration such that the fuel injection regime can be amended accordingly. Further still the specific fuel injection rate strategies discussed above with reference to table 1 and table 2 can be adjusted for example by adjusting the setpoint step values, the desired rates of combustion or fuel injection amounts. Furthermore the system can identify relationships between fuel injection level, catalytic converter temperature, and temperature rise such that the desired ramp rate can be achieved more quickly. Further still, additional information can be derived from a stored history of performance. For example when a vehicle frequently

adopts one or more specific duty cycles then the system may recognise from vehicle operational perimeters that one of those duty cycles is being entered and adjust the control strategy accordingly. For example when a certain duty cycle involves significant increases in exhaust temperature then a less intensive fuel injection regime may be instigated.

More generally it can be seen that the ramp rate varies inversely with the difference between the temperature set point and a temperature mid point immediate the upper and lower set point limits. Accordingly a more complex ramp rate regime can be obtained by, for example, selecting a "mid point" which may not be centred exactly between the upper and lower temperature set point limits and introducing appropriate constants. This can be adjusted from cycle to cycle based on recorded regeneration regime history data. Alternatively, more a complex look up table can be provided which once again can be dynamically adjusted.

Referring to Figure 4 a further improvement is shown to the arrangement where like reference numerals from other figures refer to like parts. In particular it will be seen that the fuel line 400 running to the fuel injector 22 includes a chamber portion 402 wrapped around or passing through a region containing heated water recirculated from the radiator or engine compartment . As a result fuel to the fuel injector 22 is pre-heated using waste heat as a result of which high temperatures are more easily attained.

A further improvement is shown in figure 6 whereby an electrical heater 60 is located immediately before the front face 18 of the catalytic converter 18. The main method of heat transfer from the heater 60 to the catalytic converter 18 is

via radiation. This is more efficient than using the exhaust gas to transfer heat via convection, as a large amount of power is required to get significant temperature rise of the exhaust gas.

A further enhancement of this is to catalyse the surface of the heater 60. A heater of relatively low power (500W) can achieve a significant temperature rise above the temperature of the exhaust. It is therefore possible to get the catalytic material on the surface of the heater to a temperature where it is active even when the engine is idling. This heat is then contributed to the front of the catalytic converter 18 which then achieves the main temperature rise. An additional temperature sensor 64 is located adjacent the heater and is used to allow control of the electrical power to the heater and/or the amount of fuel, in accordance with equation 2, injected, thereby preventing damage to the catalytic coating through over heating.

The various elements and components used to implement the invention will be well known to the skilled reader and do not require detailed discussion here. For example any appropriate pressure, temperature and engine speed sensors can be adopted and any appropriate fuel injector retrofitted to the exhaust manifold. The system can be controlled by a designated or existing engine control unit under software or hardware implementation of the control approach and algorithms as discussed above. The control algorithm is implemented via a microcontroller and digital logic with appropriate analogue inputs to an A to D converter. In the case the performance history of the vehicle is maintained this can be stored at memory at ECU or elsewhere in any appropriate form.

As a result of the arrangement described above, an effective and flexible exhaust filter regeneration regime control can be implemented irrespective of the vehicle type or duty cycle introduced allowing rapid and efficient regeneration whilst reducing emissions to the a minimum. Furthermore, regeneration is performed on demand, when required, rather than during a pre-determined window.

It will be appreciated the invention can be applied to any appropriate engine or fuel type and that fuel injection can take place in any appropriate part of the exhaust stream. The approaches as described above can be described to any appropriate temperature dependent exhaust treatment regime or other temperature raising mechanisms which rely on fuel injection. The fuel injection can be metered by adjusting fuel alignment, fuel injection rate or fuel injection pulse duration, fuel injection pressure variation or fuel type variation. In addition control can be implemented using appropriate sensed parameters of operation of the engine and the exhaust stream components and using any appropriate sensors and injectors.